

# Application of the WAVES Modeling Suite to the Visualization of Natural Cloud Fields

David H. Tofsted  
U.S. Army Research Laboratory  
White Sands Missile Range, NM 88002-5501

Sean G. O'Brien  
Physical Science Laboratory, Laa Cruces, NM 88003

## Abstract

The Weather and Atmospheric Visualization Effects for Simulations (WAVES) suite of codes is an integrated series of computer programs designed to simulate atmospheric scattering, absorption, and turbulence effects on electro-optical imaging systems. An adaptation of this suite has been initiated to visualize the appearance of **synthetic** clouds for use in perspective and orthographic cloud view generators. The primary models developed for this application included a new radiative transfer (RT) module optimized for dense cloud calculations and modifications to the Air Force's CSSM (Cloud Scene Simulation Model) (Cianciolo and Rasmussen, 1992). The CSSM update included incorporation of EOSAEL CLTRAN vertical structure models of particle size distribution mode radii and imposition of horizontal periodicity to allow for tiling of cloud features. The visualization routine accesses data output formats equivalent to those in WAVES. It also uses a random cloud density field equivalent in format to the CSSM output for finer spatial resolution than the RT code output. RT code limiting path radiance results are thus coupled to higher detail transmit t ante results. Reflection of incident direct and diffuse radiation by the surface is also included in the visualization package, so cloud shadows may be properly depicted.

## 1. INTRODUCTION

For some years the effect of atmospheric illumination conditions on Army electro-optical systems has focused on target contrast. This emphasis has been of limited scope primarily due to the degree of sophistication of radiative transfer models available for determining radiance conditions in the near surface atmosphere. Typically these models have tended to be only vertical structure models. Further, the focus has traditionally been limited to transmittance or contrast transmittance alone. Several models are also focused on various extinction sources such as aerosols, molecular absorber species, and Rayleigh scattering.

However, the usage of these models was limited in that one could not develop a complete understanding of the complex interactions between observer, sensor response, and observed objects within the space through which the light travels. For instance, the textures of clouds and effects due to dynamic range of radiance changes within a scene are masked within the dimensionless contrast transmission equation approach. Clouds are also more than featureless objects or simply clutter. They have structure of their own which tends to complicate a scene, creating shadow regions resulting in dynamic range effects on systems, and producing spatially varying transmittance and path radiance effects. Thus, under many circumstances 1-D models may provide reliable results. However, for more general cases a more robust code is needed.

A second issue relates to the development of connectivity between the traditional application of electro-optical analysis methods, and weather based meteorology. Many studies have focused on sensitivity to various atmospheric effects as opposed to predictive type tactical decision aids to determine systems effectiveness under varying battlefield conditions. With the advent of models such as the Battlescale Forecast Model (BFM) and COAMPS for predicting detailed information about the weather state within 24-72 hours it is technologically feasible to ask questions about the future capabilities of systems in terms of when, where, and

with what to fight. In this type application arena, we might attempt to predict the relationships between numerical weather model estimates of vertical structures of humidity and temperature on a horizontal grid, and the vertical structures of clouds and visibility in a haze layer. Once this connectivity is established, evaluation of sensor system behavior can be predicted in mission planning.

One step in this development is the ability to generate a radiance picture of the environment, given visibility as an input along with cloud layering information. From this information one may determine the illumination present at the earth's surface, positionally varying radiance, and thereby develop line of sight information. In addition visualizations of a synthetic atmosphere are possible.

## 2. CURRENT PROGRAM

In particular, our task was to generate information that could be provided to a terrain perspective view generation system called PEGASUS. Originally PEGASUS was designed to replicate the performance of a UAV or a FOG-M missile. This simulation requires an operator to direct the flight of a vehicle over terrain looking for objects at or near ground level. Clouds could become significant limitations on the ability to acquire targets under these conditions. To simulate these effects in a realtime environment, we proposed the development of a cloud overlay system, whereby vertical traces would be performed through a rendered cloud volume and transmittance and limiting path radiance would be calculated along each line of sight. This information would then be templated down into a compressed form where each 16 m x 16 m square of the template would represent a 'pixel' position in the overlay. The templating process involved a palettized format where only 256 different transmittance/path radiance indexed pairs were retained and each pixel point was mapped into one of these indices. This process was necessary to accommodate the desire of the PEGASUS developer to represent a 64 km x 64 km region at 16 m resolution.

Also needed under this application was a method for ensuring that we could evaluate the radiative transfer model outputs without overloading the capabilities of the computers at hand. To generate sufficient data to actually model a 64 km squared volume would take enormous computing power and memory. As a substitute a method was developed to horizontally wrap the results of the cloud density mapping program, and the radiative transfer program, such that the results could be tiled over the terrain.

To accomplish this, the RT program was designed with an optional periodic boundary condition. The initial radiation presented to each modeled cell of the volume was computed by horizontally wrapping the density information such that when a direct ray traced toward the source of direct radiation (the Sun or Moon) left one of the sides of the modeled volume, the computation was continued on the opposite side of the volume continuing on in the same direction. Similarly, during the iterative calculation process used to evaluate the diffuse streams present within the volume elements, diffuse streams exiting one side of the volume were used to initialize the same stream directions at the outer walls in corresponding cells on the opposite side of the volume.

Periodicity was also imposed on the results being computed by the CSSM code. CSSM is designed to ingest information about cloud type, cloud layer base height, layer depth, and percentage cloud cover by layer, and output a 3-D gridded field of cloud liquid water content data. We used the 1992 version of this model (CSSM92), which has since been updated, but which apparently exhibits the same features as the version we used. The cloud field is generated using a rescale-and-add (RSA) fractal generator. This process involves a characterization of each cloud type according to a fractal dimension, a lacunarity parameter, and characteristic length and time scales. Unfortunately, this RSA approach is incompatible with a periodic conditioning of the calculated data.

A crude forcing of periodicity was nevertheless imposed on the cloud liquid water content data. Doubtless this has corrupting effects on the overall statistics of the fractal structure of the cloud fields themselves, however it is believed that this structural damage must be accepted to avoid the worse consequences of using aperiodic data in a periodic RT code, and/or subsequent tiling applications. In particular, cases were developed before the imposition of the periodic boundary conditions in which clouds were generated that abruptly ended at the boundaries of the volume. The subsequent appearance of these clouds, where a quarter

pie shaped cloud appears in the corner of the volume, with solid and flat vertical walls of cloud along the volume boundary was deemed a worse penalty, in terms of model fidelity, than the consequences of fractal structure corruptions within the CSSM model itself.

The method used to impose periodicity was to modify the sampling method used internally by CSSM. At the subroutine level a series of 2-D arrays are maintained which characterize the base height fluctuations, vertical heating function, vertical motion function, etc. for each cloud layer. In the original model the means of generating these random fields involved a single call to an RSA algorithm for each statistic at each point. Appropriate scalings of the horizontal dimensions are used to account for distance correlations that differ depending on direction. Let us call this functional dependence  $Q(x/\sigma_x, y/\sigma_y, H, r)$ , where the output of the RSA algorithm  $Q$  is modeled as a function of the horizontal ( $x$  and  $y$ ) dimensions of the position within the volume, normalized by the scale lengths  $\sigma_x$  and  $\sigma_y$ , along with the Hurst parameter  $H$  and the lacunarity parameter  $r$ . In the modified approach developed, several calls were made to the generator, and used in a weighted average summation.

To accomplish the weighted averaging process, the weighting function

$$W(x) = \begin{cases} \frac{1}{2}[\sin(\pi x) + 1], & \text{if } -\frac{1}{2} \leq x \leq \frac{1}{2}; \\ 0, & \text{otherwise,} \end{cases}$$

is employed. Let  $X$  and  $Y$  denote the maximum horizontal dimensions of the volume to be modeled. Then the modified output from the routine calling the RSA algorithm is obtained by the sum of terms

$$Q' = \sum_{i=-1}^{i=1} W\left[\frac{(x+iX)}{X}\right] \sum_{j=-1}^{j=1} W\left[\frac{(y+jY)}{Y}\right] Q[(x+iX)/\sigma_x, (y+jY)/\sigma_y, H, r].$$

Due to the weighting function's form, minimal distortion is created in the RSA results near the center of the modeled region. However, near the midpoints of the sides of the volume 2 regions are being averaged together, and at the corners of the volume 4 samples are being averaged together. Because the random process being modeled has increased variance with increasing distance, when more than one sample is averaged the local correlations are reduced. In sample cases this has resulted in small patchy clouds around the volume boarder, of noticably shorter scale lengths than the overall structures of clouds near the center of the volume. As this was only a temporary solution to the problem, there should be some means of repairing the damage to the fractal structure by variable smoothing.

A second stage in the integration of the CSSM92 output as input to the RT code involved assessing the scattering properties of the aerosols predicted. In this effort a series of preexisting models were used. These models included the EOSAEL routines CLTRAN (Low and O'Brien, 1987) and AGAUS, and the EOSAEL database PFNDAT (Shirkey et al., 1987). CLTRAN contains a series of vertical structure models of mode radius and liquid water content as functions of height above the cloud base. In CSSM92 the only structural dependence of liquid water content based on height is given as a function of temperature. Since the database of temperature information used was based on LOWTRAN7 vertical profile tables, the vertical structure of temperature available is rather coarse. Thus CSSM92 did not do well at characterizing vertical structure of most non-cumulus cloud types. Therefore, the CLTRAN vertical structure models were substituted into the relevant parts within CSSM92. In addition, CSSM92 only output liquid water content information. But since radiative transfer models require information concerning extinction and phase function, liquid water is usually not sufficient to characterize the scattering/absorbing properties of the clouds.

Characterization of cloud scattering properties was limited because the EOSAEL PFNDAT database of phase functions contains only near surface aerosol types. The other available database of cloud phase function information, contained within LOWTRAN7, is somewhat limited in that it uses parameterizations based on the Henyey-Greenstein phase function to characterize scattering properties. But this tends to restrict the ability to model clouds.

As a result of these considerations, an approach was developed to augment the PFNDAT data set by running the AGAUS Mie scattering code for a series of particle size distributions suggested by the analysis

contained in the CLTRAN model. In CLTRAN the particle size distributions of all clouds are modeled using a modified gamma phase function. Let  $N$  be the number density of aerosol particles per unit volume. Then, let  $n(r) = dN/dr$  be the number of nominally spherical particles of radius  $r$  falling within a range  $dr$  about  $r$  in a unit volume.  $n(r)$  is called the particle size distribution, which for a modified gamma distribution is given by:

$$n(r) = \frac{dN}{dr} = A r^\alpha \exp [-br^\gamma].$$

All the particle size distribution functions in CLTRAN use a modified gamma distribution function with  $\alpha = 2$  and  $\gamma = 1$ , and where  $A$  and  $b$  are functions of the particle distribution mode radius  $\tilde{r}$ . The CLTRAN model development thus gives a simple method for characterizing cloud phase functions: by running AGAUS for a standard liquid water content value at varying mode radius values.

Twenty new phase functions were developed, where mode radius varied from around 1 to 30  $\mu\text{m}$ . The use of CLTRAN vertical structure models of mode radius within CSSM allows the characterization of the phase function and the optical extinction properties of clouds as functions of position with a simple extension to CSSM.

The phase functions created, along with the phase functions contained in PFNDAT were then analyzed using a processing routine to express their angular behavior as a Legendre series expansion and a forward scattering peak fraction. When evaluating the forward peak fraction the original Legendre coefficients, derived by analysis of the phase function, must be modified.

### 3. PHASE FUNCTION DELTA CORRECTION

The modification of phase function Legendre coefficients is a result of applying the forward scattering correction. Consider a general expression for the radiative transfer equation as given by

$$\nabla I(\hat{\Omega}) + \sigma I(\hat{\Omega}) = \varpi \sigma \int_{4\pi} I(\hat{\Omega}') P(\hat{\Omega}, \hat{\Omega}') d\Omega' + (1 - \varpi) \sigma B$$

Here,  $I$  is the radiance in the direction of the unit vector  $\hat{\Omega}$ .  $d\Omega$  represents a differential solid angle.  $\sigma$  is the extinction coefficient,  $w$  is the single scattering albedo (or probability that a scattering event occurs, given a collision with a particle),  $B$  is the blackbody function of temperature and wavelength. Therefore, the second term on the right represents emission of energy, while the first term on the right represents scattering, where  $\varpi\sigma$  equals the scattering coefficient. The function  $P(\hat{\Omega}, \hat{\Omega}')$  represents the probability of energy entering from direction  $\hat{\Omega}'$  and exiting in direction  $\hat{\Omega}$  given that a scattering event occurs. This function is also referred to as the phase function.

For most natural aerosols  $P$  is highly peaked in the forward direction. As a result it is often difficult for a low order Legendre expansion to adequately characterize the forward scattering properties of most aerosols. Therefore, a typical technique used to improve the model of the scattering process is to assume that a fraction  $f$  of the energy actually scatters in the forward direction, and model this portion using a  $\delta$  function:

$$P(\hat{\Omega}, \hat{\Omega}') \approx f \delta(\hat{\Omega}, \hat{\Omega}') + (1 - f) P'(\hat{\Omega}, \hat{\Omega}'),$$

where the Legendre components of the  $P'$  phase function have been altered to reflect the removal of the forward peak.

Introducing this form for the phase function into the integral on the right hand side of the equation of transfer we find:

$$\varpi \sigma \int_{4\pi} I(\hat{\Omega}') P(\hat{\Omega}, \hat{\Omega}') d\Omega' = \varpi \sigma f I(\hat{\Omega}) + \varpi \sigma (1 - f) \int_{4\pi} I(\hat{\Omega}') P'(\hat{\Omega}, \hat{\Omega}') d\Omega'.$$

Introducing this form back into the RT equation, we can translate the term in  $I(\hat{\Omega})$  to the left-hand-side and introduce the variables:

$$\sigma' = \sigma(1 - \varpi f); \quad w' = \varpi(1 - f)/(1 - \varpi f).$$

These modified forms of the extinction coefficient and single scattering albedo allow us to model the RT equation using the same form as the original equation, except that the forward peak to the phase function has been removed. This approach is also referred to as a scaling transformation (McKellar and Box, 1981). Space does not allow a full detailing of the means of altering the Legendre coefficients here.

#### 4. WAVES MODELING SUITE

The WAVES (Weather and Atmospheric Visualization Effects for Simulations) suite of codes provided the basis for generating the products used by the visualization software. WAVES was designed initially for characterization of illumination conditions and line of sight propagation effects. Products were also generated from WAVES to provide formatted information on cloud shadowing effects over terrain and 3-D radiance conditions within a scattering volume. However, the radiative transfer model contained in WAVES (the BLIRB (Boundary Layer Illumination and Radiation Balance) model) was optimized for optically thin media such as hazes. When this model was applied to optically thick media, such as clouds, the computer systems on which the models were run did not contain enough RAM to treat the clouds with adequate resolution. In addition, though visualization software had been prototype under WAVES, this software did not render visually realistic cloud scenes. A three-fold program was therefore followed to enhance the performance obtained under WAVES: Conceptually, the first phase, previously described, augmented the CSSM92 output and available phase function databases to allow cloud characterization. In the second phase a new radiative transfer code called BLITS (Boundary Layer Illumination and Transmission Simulation) was developed. The third phase involved the adaptation of a visualization code previously developed to render the outputs of the BEAMS radiative transfer code (Hoock et al., 1992). This adapted visualization code has been named VIS42, since it is designed to operate on WAVES FastVIEW preprocessor formatted output which generates limiting path radiance information using a set of 42 directions. Interpolations are then conducted over these 42 directions in each modeled cell of the volume.

#### 5. BLITS RADIATIVE TRANSFER MODEL

The BLITS model has been optimized for treating cloud aerosols of any density within each scattering cell of the modeled volume. The model is designed as a pure radiative transfer model with all information regarding scattering properties of the individual cells being passed off to a controller module at a higher level in the coding architecture. In our case, this means there exists a model (called the Applications Implementation Manager (AIM)) which provides a user interface, calls the CSSM92 model, generates processed input data for running BLITS, and analyzes the outputs of BLITS, in a single overall packaged environment. This means that BLITS can be used for a number of different applications, where the RT model stays constant, but the interface changes.

The main routines in BLITS ingest the input data, provide output to various files, precompute radiative transfer properties between different faces of each scattering cell type, evaluate direct radiation transmitted from the top of the modeled volume to each cell wall within the volume, and run the iteration routine that relaxes the system toward its final radiation balance state. Due to the large amount of data computed prior to starting the relaxation routine, no complicated exponentiation operations are conducted within the inner loops of the model, improving model performance. However, this means that large data arrays are maintained, and thus only a limited number of scattering classes are allowed. The current model limits the number of cell types to 80, which is a reasonable number for the 64 MB system used. For a volume . 4 km deep and with a vertical resolution of 1/4 km, or 16 layers, this means that if each of the horizontally homogeneous haze layers is provided its own scattering class, only 64 classes remain with which to classify the other cells. Presumably these are all the cells containing cloud elements. The question is then how to characterize the remaining cells. The solution comes via a pattern recognition algorithm contained in the AIM interface.

## 6. VIS42 VISUALIZATION CODE

The VIS42 visualization program is designed to visualize the cloud radiance features being produced by the BLITS model and its post-processed output. To accomplish this the VIS42 model reads in the output data from BLITS that has been post-processed into a form identical to that used by the WAVES FastVIEW object code. This data set includes the output of a templating approach similar to that used in dividing the volume cells into different cloud types to be input to the BLITS model. To begin, each scattering cell within the volume is characterized by a set of 42 limiting path radiances in 42 directions. The templating scheme involves generating a limited set of 42-component vectors which characterize the directional dependence of these limiting path radiances across the volume. Then, when the output data for a given cell is produced all that need be output is the index of the appropriate template, the maximum limiting path radiance for this cell, and the transmission coefficient. The header to the FastVIEW file contains the information concerning these templates.

VIS42 reads this data set and develops a splining interpolation procedure for determining the limiting path radiance in any direction of user interest. VIS42 also reads an output that provides separate transmittance information concerning each scattering cell. VIS42 has the option of using data in the transmission file of the same granularity as the data contained in the FastVIEW file, or using the high resolution transmission file data. This methodology follows an approach suggested by Hooek et al. (1992): Since limiting path radiance is generally a slowly varying function of position, representing an integrated quantity, and since transmittance can vary rapidly within a medium, it should be possible to couple a higher resolution density structure calculation to a coarse resolution radiative transfer solution in performing a rendering task. In our test cases the transmittance data were available at 1/16 km resolution, while the radiance data were computed at 1/4 km resolution.

Using this approach, the transmission data file representing the modified extinction coefficient data for the cells ( $\sigma'$ ) is output to a file identical in form to the original CSSM92 output format. This data is then used in VIS42 in a first phase calculation. In this phase, for an orthographic rendering of the modeled volume, a maximum of three outer walls of the rendered volume may be visible. Points are chosen at the centers of each of the fine grid transmission data outer wall cells. For each of these points a line of sight is traced through the volume to determine the integrated transmission and path radiance. The code then proceeds to a second phase.

In the second phase the image rendering is accomplished. Each pixel is first assigned an original radiance value according to some algorithm. In the current implementation the 8 km x 8 km modeled ground is rendered as a green reflecting surface. If the observation direction is downward and the line of sight is oriented toward a point on the surface, the surface brightness is modeled using the green surface reflectance coefficients, along with illumination information passed to VIS42 via the IL. OUT processed surface illumination file. This file contains surface illumination information that has been weighted to represent the normalized irradiance present at a surface element characteristic of the received signal of a sensor modeled by a weighting response function. For any point that is not part of the surface below the modeled volume a second set of results is used. This set represents the mean diffuse radiance present at the top of the modeled atmospheric volume, as weighted according to the same sensor response function. Once the initial channel based radiances are set, the code looks into its table of transmission cell centered propagation results and determines a subset of these results that represents near neighbors in terms of distance on a plane through which a series of parallel lines of sight are drawn through the modeled volume. Given this set of near neighbors, the algorithm determines weight factors of these neighboring points and determines the weighted sum of transmission and path radiance effects to apply to this pixel. Once a weighted sum is computed, the results are divided by the total weight factor, the initial radiance value is multiplied by the net transmittance, and the net path radiance is added, channel by channel. For example, a human eye perceives effects using red, green, and blue color channels. Thus the routine would determine 3 applied weighted transmittance/path radiance sets which would be applied individually to the different channels to determine the final pixel color value.

Pixel values are first computed using channel-based, floating point radiance units. Once all pixel results have been evaluated, the results are converted to an integer pixel scale by finding the maximum floating

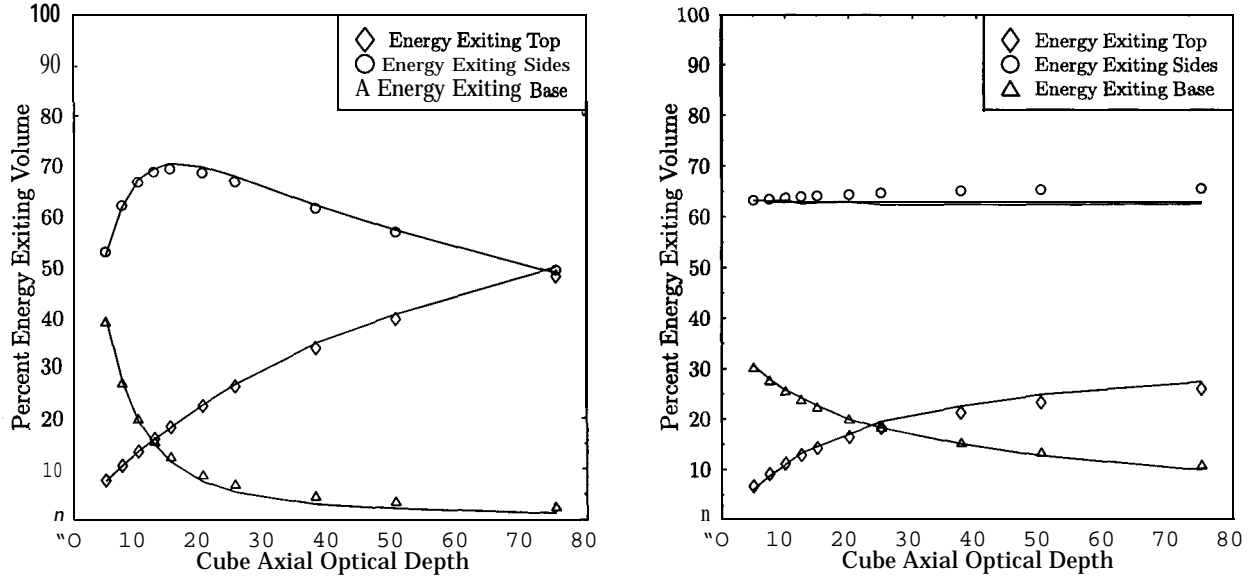


Figure 1: Comparison of BLITS radiative transfer model performance with Monte Carlo model results.

point result in any of the up to three color channels and mapping this value into a number 255.999. All other results are mapped linearly with respect to this mapping into the same range. Following this mapping all results are truncated to integer results, ensuring that the final image pixel values are limited to the range of 0 to 255, which is a 24-bit (8 bits per color channel) color image.

## 7. RESULTS

The radiative transfer program briefly described above was run and compared with the results of a Monte Carlo model. The scenarios tested were equivalent to the scenarios developed by McKee and Cox (1974). The shape of the scattering volume was cubical. A pure scattering medium ( $\varpi = 1$ ) of up to 75 optical depths thickness along one axis was used. The exterior to the volume was considered a black void, except for a uniform plane parallel source of direct radiation incident at the top of the volume with a varying zenith angle of 0°, 30°, or 60° with respect to the normal of the upper surface. At angles greater than 0° the radiation also fell on the 'eastern' wall of the volume. Figure 1 shows the results for incident angles of 0° and 60°. Comparison of the results with the Monte Carlo model output shows the BLITS model performance is very good. The discrepancies which occur for energy exiting the sides of the volume are perhaps related to the limited extent of the Legendre expansion of the phase function. In the cases run, a 24-stream scattering model was used which supports up to a fourth order Legendre polynomial expansion. The comparisons were made using a fourth order expansion. For this order the forward peak fraction for most aerosols is around 50 percent. Thus after forward peak removal the total effective optical depth treated is around a maximum of 40 for the 75 optical depth case. In the examples shown, the grid used to simulate these results was a 4x4x4 representation. Each cell in the volume thus had to simulate 10 optical depths of scattering material. In previous comparisons of model results with Monte Carlo data the RT code tested was typically run using a 40x40x40 volume representation in an 8-stream model. The differences were that for an 8-stream representation approximately 75 percent of the expansion was modeled by the forward peak. Thus the maximum effective optical depth modeled per cell was only around 0.5, and the current results imply that the current model can treat significantly thicker clouds at reduced cost in memory and time than previously possible.

In figure 2 the results of the VIS42 visualization code are shown. A two cloud layer atmosphere has been modeled. The upper layer is an altostratus type. The lower layer is a cumulus layer of approximately

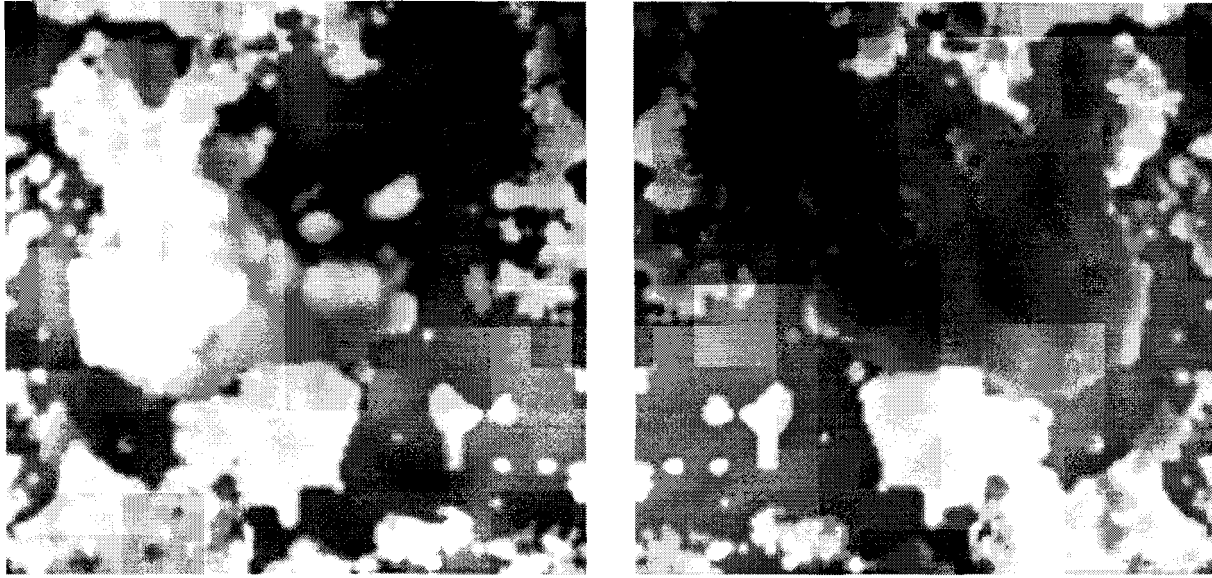


Figure 2: Downward (left-hand side) and upward (right-hand side) looking views of a cloud field

35 percent cloud cover beginning at 1 km above the modeled surface. Two views are given of the scene: One shows the appearance of the clouds from above, looking at a rendered surface below the atmospheric volume. The other shows the clouds as they appear in orthographic rendering when looking upward.

In figure 3 we show a prototype image modification process result using a templated version of the vertically downward looking appearance of the cloud volume to modify a cloudfree initial scene. The original scene is shown on the left side. This scene is assigned a mean reflectance value  $\bar{\alpha}$ . Based on this value, one can analyze the image contents and deduce a mean pixel value  $P$ . From this information the point-to-point reflectivities present in an image may be calculated: Let  $p_{i,j}$  be a pixel RGB value at position  $(i,j)$ . The point reflectance is then modeled as  $\alpha_{i,j} = (\bar{\alpha}/\bar{P})p_{i,j}$ . Using the positionally varying illumination information available, the brightness of that pixel can be determined as a channel-based radiance result. The limiting path radiance and transmittance effects for that point can then be applied. This process takes about 6 seconds on an SGI computer, which also entails reading the databases of transmittance/path radiance and illumination information, as well as the mean pixel calculation.

## 8. CONCLUSIONS

We believe that the modeling framework developed provides a reasonable approach to rendering natural clouds in currently available visualization software. Prototype rendering techniques developed for operation with the Naval Postgraduate School's PEGASUS Perspective View Generator are capable of rendering a templated cloud image within 6 seconds. However, this prototype software contains no optimization, requires all data to be read into the model, and operates on 3 color channels for each pixel. Obviously more sophisticated software could radically reduce rendering time of this 2-D templated cloud effect, resulting in "realtime visualization of 2-D clouds. On the other hand, more robust 3-D cloud rendering routines may require significant additional effort to move to a near-realtime performance. Current orthographic rendering rates of 5 minutes per frame are far from reaching realtime. However, the fidelity possible with the orthographic model developed shows significant improvements over previous capabilities, and uses may still be available for these non-realtime technologies.

We anticipate further connectivity to gridded weather data and/or satellite derived real cloud fields. These connections should improve the ability to provide high fidelity virtual simulations. Utility of these

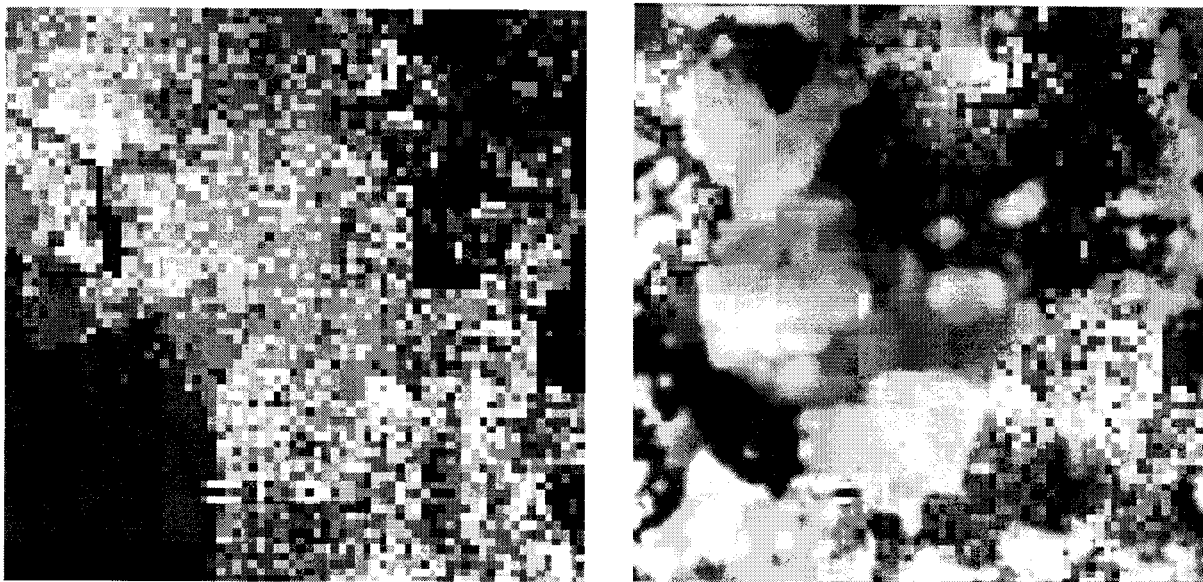


Figure 3: Original image of surface (left-hand side) and modified image following application of cloud transmission and path radiance effects (right-hand side).

simulation results should allow for better predictions of systems performance in mission planning software. Additionally, the ability to tile the simulated region across a large area is advantageous since in a DIS/HLA environment it reduces the amount of data that must be passed over a network. Lastly, the WAVES environment appears to provide useful output data formats. However, given the desire to present realistic clouds, a higher resolution extinction coefficient field appears advantageous in providing low level detail in the rendering of clouds.

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